ANNALS OF THE NEW YORK ACADEMY OF SCIENCES

VOLUME 93 ARTICLE 1, PAGES 1-24

VERTICAL TAKE-OFF AND LANDING (VTOL) ROTORLESS AIRCRAFT WITH INHERENT STABILITY

By

I. B. LASKOWITZ

NEW YORK
PUBLISHED BY THE ACADEMY
APRIL 28, 1961

The Sections and the Divisions hold meetings regularly, one evening each month, during the academic year, October to May, inclusive. All meetings are held at the building of The New York Academy of Sciences, 2 East Sixty-third Street, New York 21, New York.

Conferences are also held at irregular intervals at times announced by special programs.

ANNALS OF THE NEW YORK ACADEMY OF SCIENCES

VOLUME 93 ARTICLE 1. PAGES 1-24
APRIL 28, 1961

VERTICAL TAKE-OFF AND LANDING (VTOL) ROTORLESS AIRCRAFT WITH INHERENT STABILITY

By

I. B. LASKOWITZ
Laskowitz Helicopter Company, Incorporated, Brooklyn, N. Y.

ACCORDED THE D. B. STEINMAN AWARD FOR RESEARCH IN STRUCTURAL ENGINEERING IN 1960 BY THE NEW YORK ACADEMY OF SCIENCES

NEW YORK
PUBLISHED BY THE ACADEMY

VERTICAL TAKE-OFF AND LANDING (VTOL) ROTORLESS AIRCRAFT WITH INHERENT STABILITY*

I. B. Laskowitz

Laskowitz Helicopter Company, Incorporated, Brooklyn, N. Y.

ACCORDED THE D. B. STEINMAN AWARD FOR RESEARCH IN STRUCTURAL ENGINEERING IN 1960 BY THE NEW YORK ACADEMY OF SCIENCES

Introduction

A VTOL aircraft[1] has been defined as one that takes off vertically, changes from hovering to forward flight, cruises to its destination, resumes hovering flight, and then performs a vertical landing. Depending on the means of propulsion, VTOL aircraft may be divided into five basic types: rotor, propeller, ducted fan, turbojet or other gas producer, and rocket, in the order of ascending speed capability. Helicopters[1] depend on their rotors to furnish the lift, and on their propulsive forces for hovering and forward flight. Two intermediate types resulting from a combination of the basic types are the rotor-propeller and the rotor-turbojet, in which the rotor is used for hovering flight and the propeller or turbojet for forward flight. This combination produces machines having all the advantages of the rotor as well as the high-speed advantages of the propeller or turbojet.

It is well recognized that the use of rotors in direct lift aircraft provides the important safety feature of autorotational descent of the craft in an emergency, as in engine failure. However, rotors are costly and add weight and complexity to the aircraft; accordingly, their elimination is desirable if a degree of safety is provided in certain operations by the use of multiple turbojet engines or other units having a high power or thrust-to-weight ratio. It is also desirable for direct-lift aircraft to take off and land in a horizontal attitude and thereby eliminate the need for complex auxiliary ground cranes and gear. Furthermore, it is desirable that the lift thrust (T) of the engine or engines be concentrated at the center of thrust (CT) directly above the center of gravity (CG) where the weight (W) of the aircraft is centered in order that a freely suspended, vertical exhaust nozzle may be utilized to provide inherent stability.

Another desirable feature in VTOL aircraft is the "ejector-effect" principle used in conjunction with the turbojet engine to augment the thrust of the engine vertically and horizontally; at the same time it reduces the specific fuel consumption, noise level, temperature, and velocity of the jet. This principle also maintains the simplicity of the basic turbojet engine without requiring additional rotating parts as in the turbofan engine or lift-fan engine that has a fan in the fuselage or wing.

Rotorless VTOL Aircraft Concept

FIGURES 1-4 illustrate the application of the turbojet engine to conceptional rotorless VTOL aircraft, incorporating the desirable features referred to above. As shown, the exhaust from one or three turbojet engines may be directed, when desired, either vertically (for hovering and vertical flight) or horizontally (for high speed forward flight). This diversion is accomplished by a rotary control valve. Freely suspended is the ball-bearing gimbal-mounted vertical exhaust nozzle, the ends of which are connected to the universally mounted control stick. Movement of the control stick in any direction will correspondingly tilt the exhaust nozzle and thus vary the direction of the lift thrust longitudinally or transversely as indicated by the dot-and-dash lines and arrows. This variation in thrust is similar to that produced in the rotor of a helicopter by cyclic pitch change of the rotor blades. Aileron and elevator controls are also connected to the control stick for use in forward flight. Compressed-air bleed valves operated by conventional foot pedals provide jet-steering control for hovering and vertical flight, while rudder controls are connected to the foot pedals for use in forward flight. Supplemental lateral and longitudinal stability-control jets, in hovering and vertical flight, are provided and operated by the control stick. The connections to the control stick and foot pedals are such that the various forces act in the same sense or direction to supplement one another for better stability and control of the aircraft.

As will be readily observed, the vertical and horizontal exhaust nozzles discharge through circular openings, open at both ends, to produce ejector effects, drawing in secondary air from the two side air inlets that intermingles with the gas jets to augment the thrust, reduce the specific fuel consumption, reduce the noise level, and reduce the temperature and velocity of the jet.[2]

As indicated in FIGURE 4, since the vertical exhaust nozzle is freely suspended while the hands of the pilot are off the control stick, the nozzle always tends to assume a vertical position by the action of gravity, and gas discharges through it in hovering and vertical flight. A stabilizing moment ($SM = T \times a$) is produced when the horizontal axis 6–6 of the aircraft is inclined either laterally or longitudinally to position 7–7, endowing the aircraft with inherent (hands-off-control stick) stability in this condition of flight. Since the vertical exhaust nozzle tends to assume a vertical position (whether gas is discharging through it or not) in forward flight with hands off the control stick, the nozzle moves freely with the control stick to effect the aileron and elevator forces that produce stabilizing moments when the aircraft is inclined either laterally or longitudinally and that give the aircraft inherent sta-

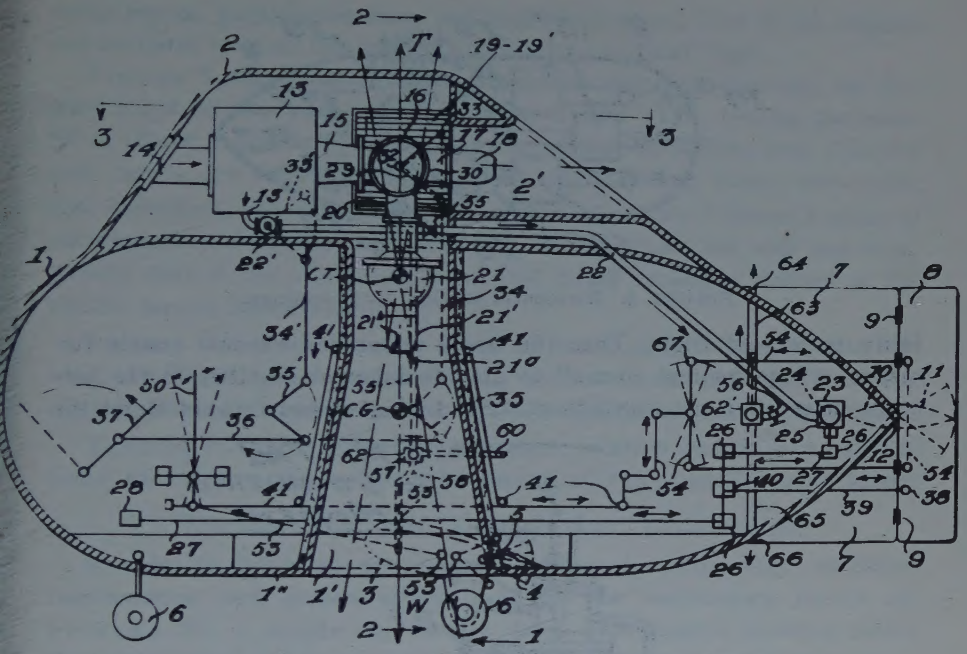


FIGURE 1. Longitudinal section: one engine.

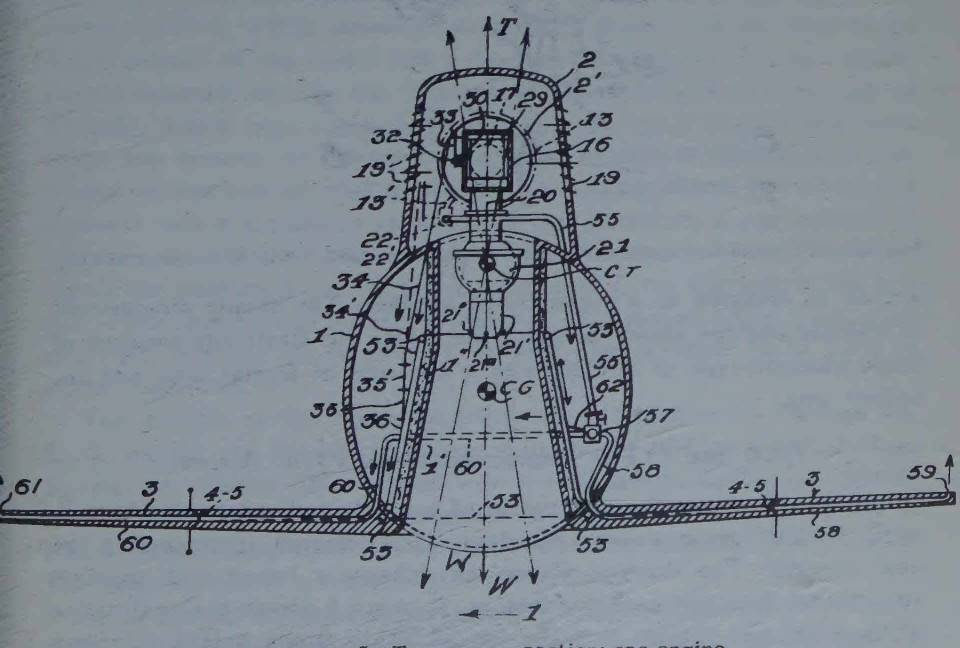


FIGURE 2. Transverse section: one engine.

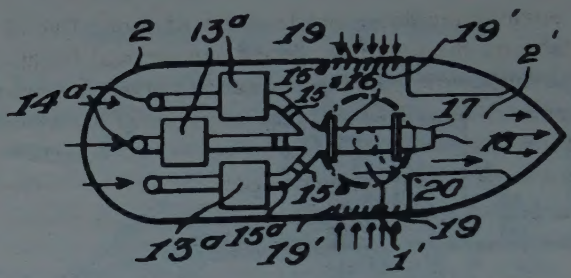


FIGURE 3. Horizontal section: three engines.

bility in forward flight. Thus the freely suspended exhaust nozzle furnishes a "mechanical means" to provide inherent stability to the aircraft under all flight conditions (4,5). In high-speed forward flight the

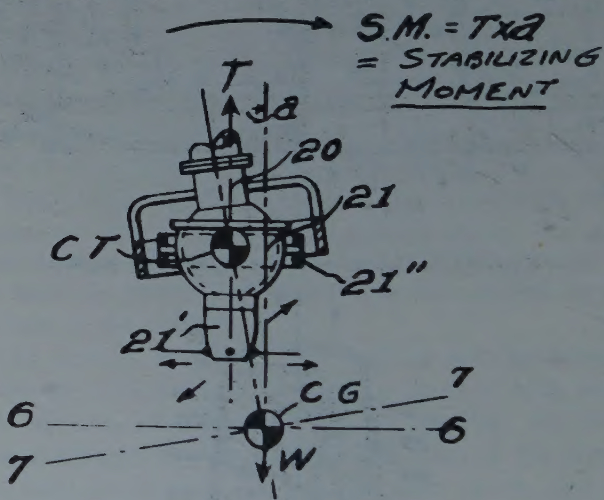


FIGURE 4. Force and moment diagram: gimbal-mounted, vertical exhaust nozzle.

aircraft is operated as a conventional airplane. The simple arrangement of multiple engines shown, provides the safety and flexibility required of large transport-type of aircraft with a minimum of frontal area and resultant drag.

1,800 and 18,000 Pounds Rotorless VTOL Aircraft

FIGURE 5 shows the application of a single turbojet engine to a 2-seat, 1800-lb. gross weight, rotorless VTOL aircraft incorporating the new concept. The drawing shows the schematic layout and supplies engineering data and load distribution. FIGURE 6 shows the application of three turbojet engines to a 10-seat, 18,000-lb. gross weight, rotorless VTOL aircraft also embodying the new concept and showing the sche-

matic layout, engineering data, and load distribution. Two of the engines are designed to carry the load in hovering and vertical flight.

FIGURE 7 shows anticipated performance curves in hovering and forward flight for the 2-seat, 1800-lb. gross weight VTOL without the benefit of thrust augmentation by the ejector effect. At speeds from 0 to 610 mph curves are shown giving; required engine thrust, range, endurance, fuel consumed, and miles per gallon of fuel. FIGURE 8 shows a group of anticipated performance curves for the same machine but with one seat, namely that of the pilot, 800 lb. of fuel being available instead of the 600 lb. for the 2-seat machine.

FIGURE 9 shows a similar group of performance curves for the 10-seat, 18,000-lb. gross weight VTOL, again without the benefit of the ejector effect, at speeds from 0 to 1520 mph (Mach No. 2), sea level.

TABLES 1-3 show typical, approximate, relative performance calculations upon which the performance curves of FIGURES 7-9 were based.

"Ejector-Effect" and "Ground-Effect" Determination

In order to determine the numerical value of ejector effect or thrust augmentation and ground effect (2,3) on the performance curves of FIGURES 7-9, a simple one twelfth scale experimental dynamic model was constructed and is shown in the upper right hand corner of FIGURE 10. The model represents to scale the central vertical opening of the 2-seat, 1800-lb. VTOL shown in FIGURE 5. Wings were attached to the lower portion of the model and a compressed air pipe with an exhaust nozzle inserted near the top. A pressure gage indicated an air supply of 12 psig, which was maintained throughout the test. A split removable plate was mounted on the top of the model to prevent admission of secondary air but was removed to measure the ejector effect. The model was mounted above a platform representing the ground on a pan balance to measure the lift or thrust with and without ejector effect. The height above the platform H was varied in relation to D the diameter at the bottom of the opening and the lift or thrust L_e with ejector effect (split plate removed) and the lift or thrust L without ejector effect (split plate in place) measured.

The results of the tests are tabulated and plotted in FIGURE 10. L_e/L equals the lift or thrust augmentation by ejector effect. L/L_{max} equals the relative lift or thrust with ground effect. $L_e/L_{e(max)}$ equals relative lift or thrust with ground effect. Note that the maximum lift or thrust augmentation of 2.5 occurs at a minimum height of $H/D = 1.55$. The augmentation at a height of $H/D = 0.93$ is 2.0.

Since the lift or thrust augmentation by ejector effect results from no additional energy or fuel consumption the performance curves of FIGURES 7-9 reflecting the benefit of ejector effect should be improved from 2.0

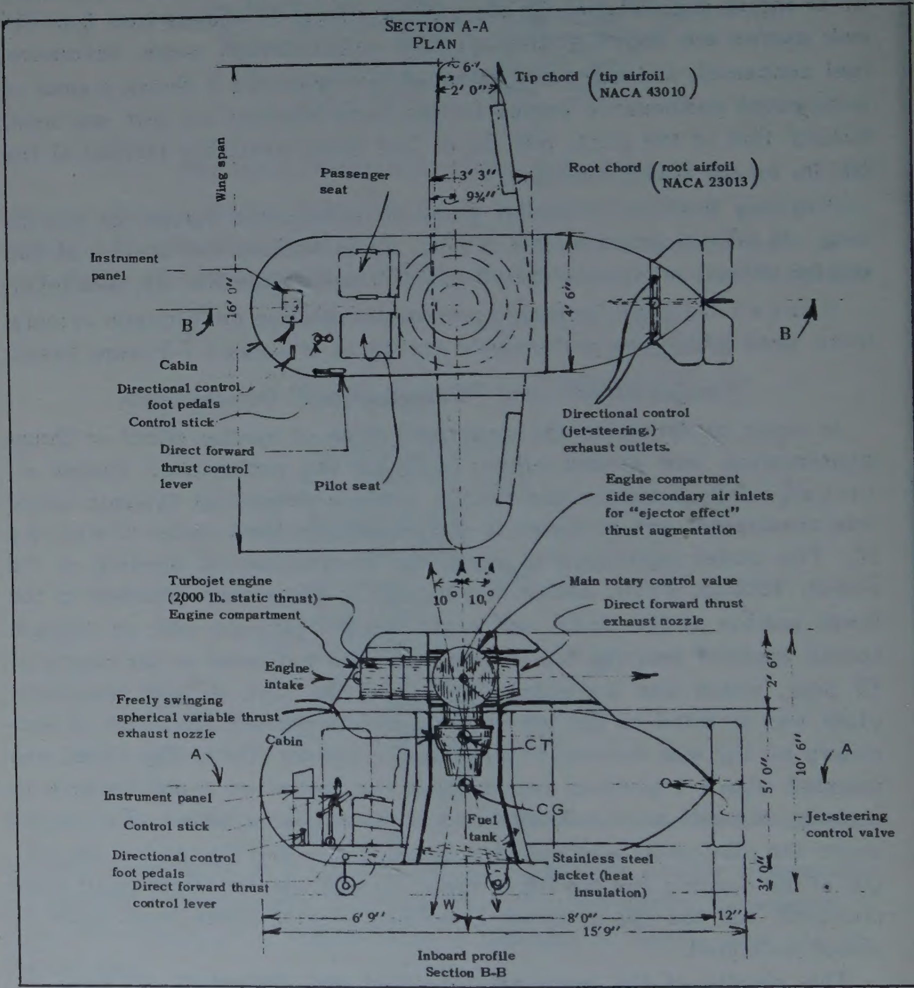


FIGURE 5. Jet-powered rotorless VTOL, 1800-lb gross weight; schematic lay-engineering data.

to 2.5 times over that shown inasmuch as for a given thrust the specific fuel consumption will be relatively 1/2.0 to 1/2.5 of that used. Another aspect of the improved performance is that for a required engine thrust using ejector effect, a much smaller engine having a thrust of 1/2.0 to 1/2.5 of that required would suffice. Using the same specific fuel consumption, the fuel consumed per hour will be 1/2.0 to 1/2.5 of that used; for a given available fuel, the range, endurance, and miles per gallon of fuel will be 1/2.0 to 1/2.5 times greater. Other benefits result from the smaller engine, in weight, space, and frontal area.

Turbojet and Turbofan Engines

FIGURE 11 is a comparative diagram of the General Electric J85 turbojet and CF700-1 turbofan engines. As indicated, the turbofan engine consists of the basic J85 turbojet engine with the tailcone replaced by a fan assembly consisting of a single-stage, free-floating turbine, with tip-mounted compressor blading and concentric jet nozzles. The turbine extracts energy from the engine exhaust gases to drive the aft fan that compresses a secondary flow of air, increasing the total mass air flow

---

Engineering data:

Wing - tapered NACA 23013-43010 (report no. 627)
Wing area - S = 40.6 sq. ft.
Wing span - 6 = 40.6 sq. ft.
Aspect ratio - $AR = \frac{6^2}{S} = \frac{16^2}{40.6} = 6.31$

Effective wing area = 28.6 sq. ft.
Frontal area - fuselage and engine compartment = 31.7 sq. ft.
Tail surfaces — additional = 5.2 sq. ft.

Load Distribution:

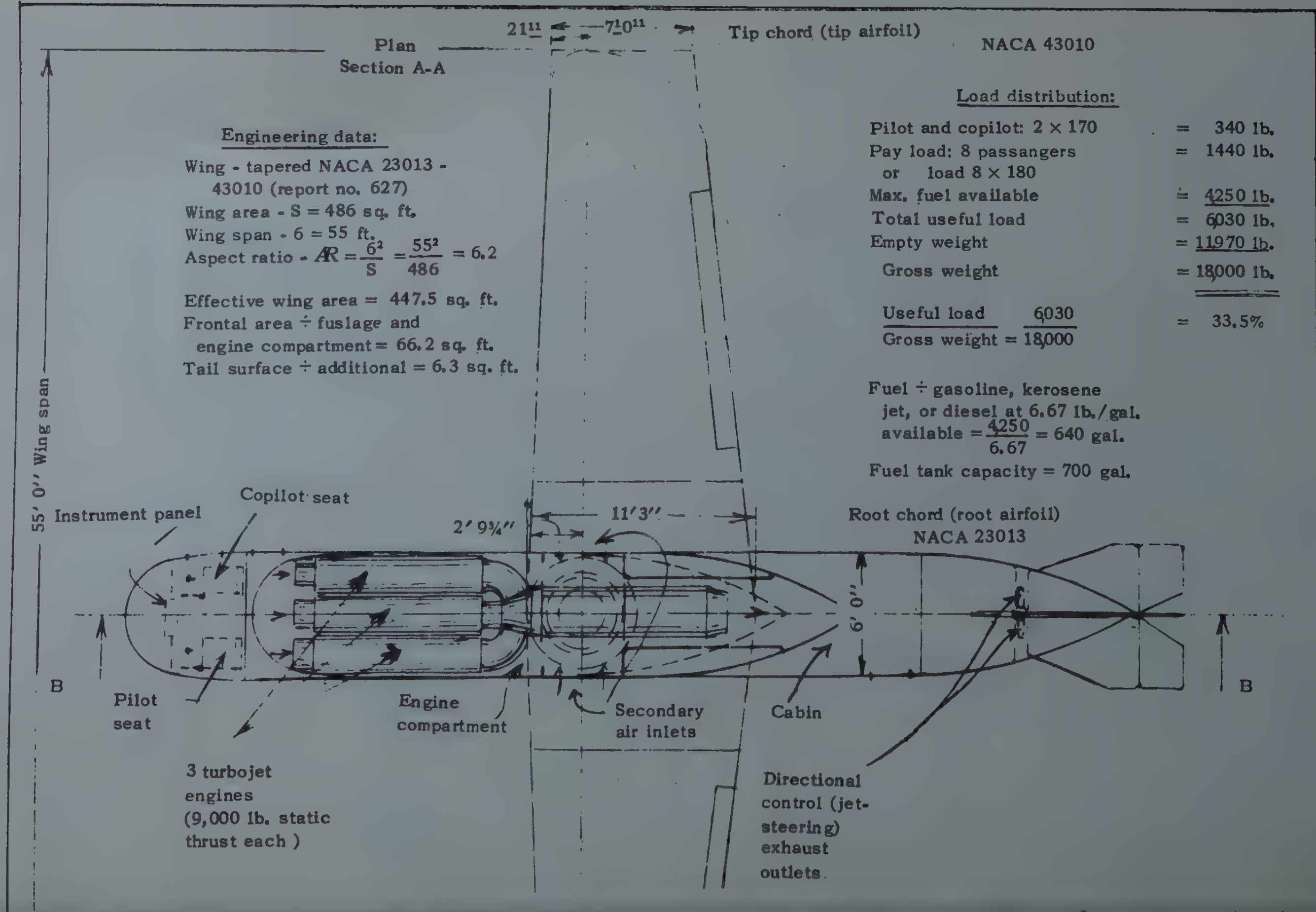
Pilot	= 170 lb.
Pay load - 1 passenger (+ baggage)	= 200 lb.
Max. fuel available	= 600 lb.
Total useful load	= 970 lb.
Empty weight	= 830 lb.
Gross weight	= 1,800 lb.

$\frac{\text{Useful load}}{\text{Gross weight}} = \frac{970}{1800} = 53.8\%$

Fuel: gasoline, kerosene jet, or diesel at 6.67 lb./gal.
available $= \frac{600}{6.67} = 90$ gal.
Fuel: available pilot only $= \frac{800}{6.67} = 120$ gal.

Fuel tank capacity = 120 gal.

scale: ¼″ = 1 foot


Plan
Section A-A
2′11″
7′0″
Tip chord (tip airfoil)
NACA 43010
Engineering data:
Wing - tapered NACA 23013 - 43010 (report no. 627)
Wing area - S = 486 sq. ft.
Wing span - 6 = 55 ft.
Aspect ratio - $AR = \frac{6^2}{S} = \frac{55^2}{486} = 6.2$
Effective wing area = 447.5 sq. ft.
Frontal area ÷ fuslage and engine compartment = 66.2 sq. ft.
Tail surface ÷ additional = 6.3 sq. ft.
Load distribution:
Pilot and copilot: 2 × 170 = 340 lb.
Pay load: 8 passangers or load 8 × 180 = 1440 lb.
Max. fuel available ≐ 4250 lb.
Total useful load = 6030 lb.
Empty weight = 11970 lb.
Gross weight = 18000 lb.
$\frac{\text{Useful load}}{\text{Gross weight}} = \frac{6030}{18000} = 33.5\%$
Fuel ÷ gasoline, kerosene jet, or diesel at 6.67 lb./gal.
available = $\frac{4250}{6.67}$ = 640 gal.
Fuel tank capacity = 700 gal.
Root chord (root airfoil)
NACA 23013
55′ 0″ Wing span
Instrument panel
Copilot seat
2′ 9¾″
11′ 3″
6′ 0″
B
B
Pilot seat
Engine compartment
Secondary air inlets
Cabin
3 turbojet engines (9,000 lb. static thrust each)
Directional control (jet-steering) exhaust outlets

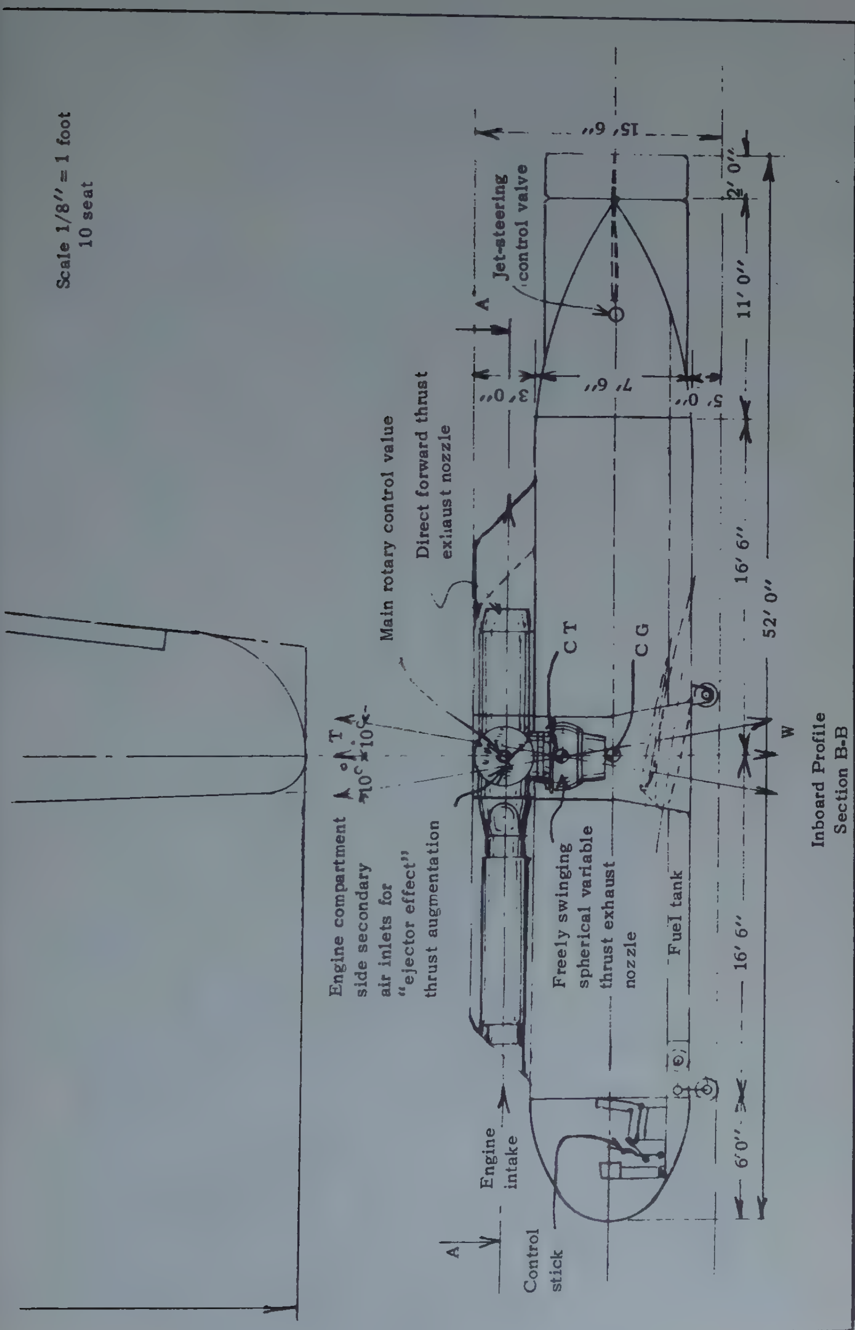


FIGURE 6. Jet-powered rotorless VTOL, 18,000-lb. gross weight; schematic layout and engineering data.

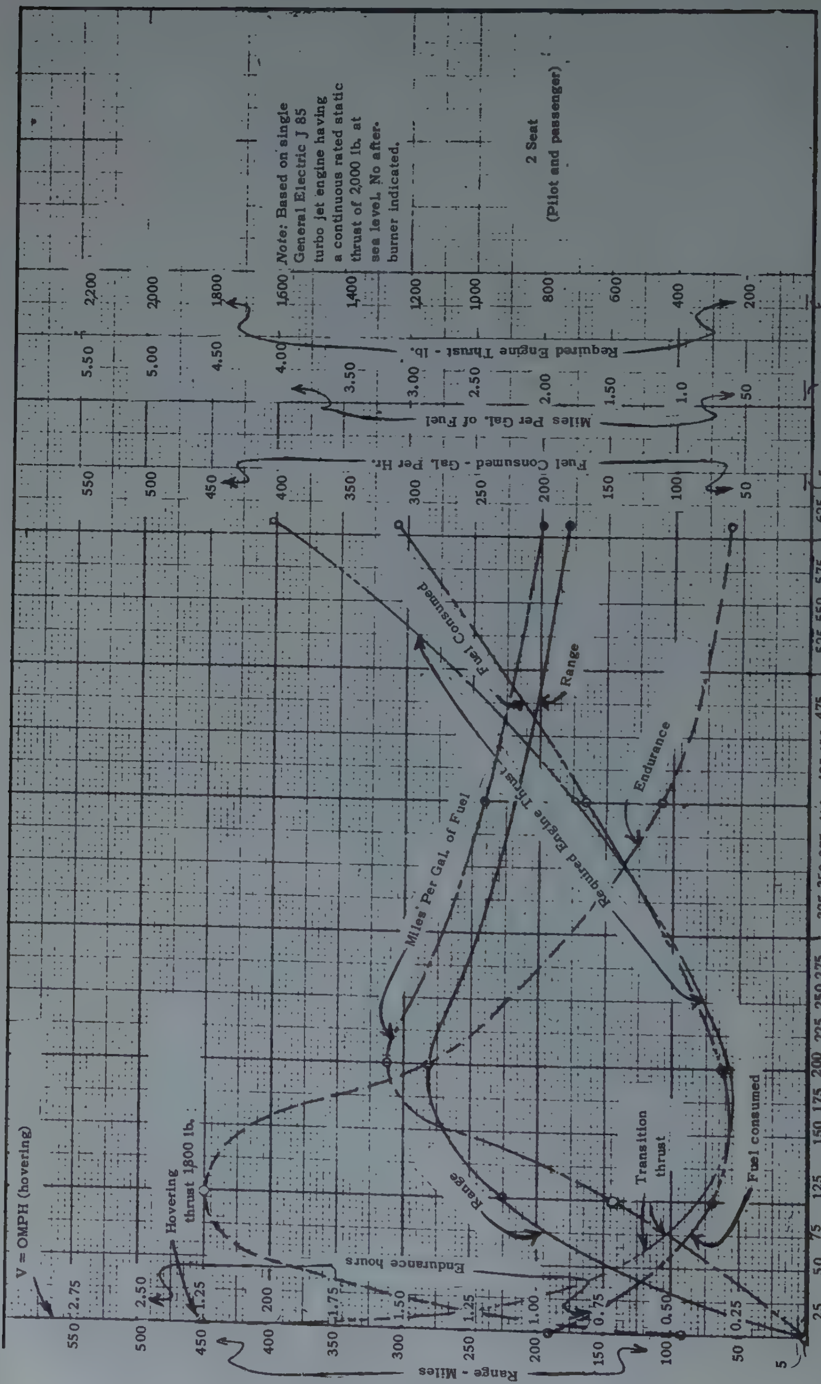


FIGURE 7. Jet-powered rotorless VTOL, 1800-lb. gross weight, 2 seat: performance curves.

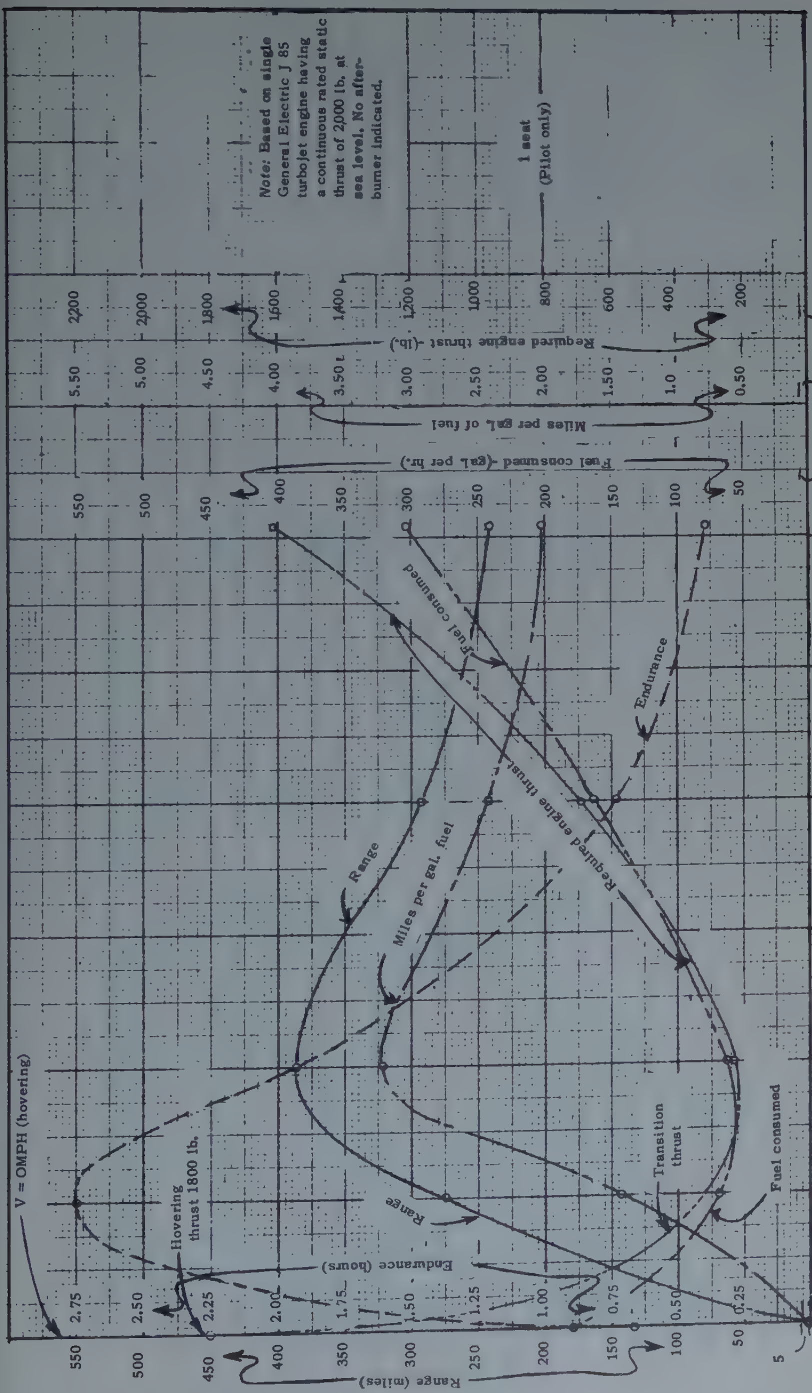


FIGURE 8. Jet-powered rotorless VTOL, 1800-lb. gross weight, 1 seat: performance curves.

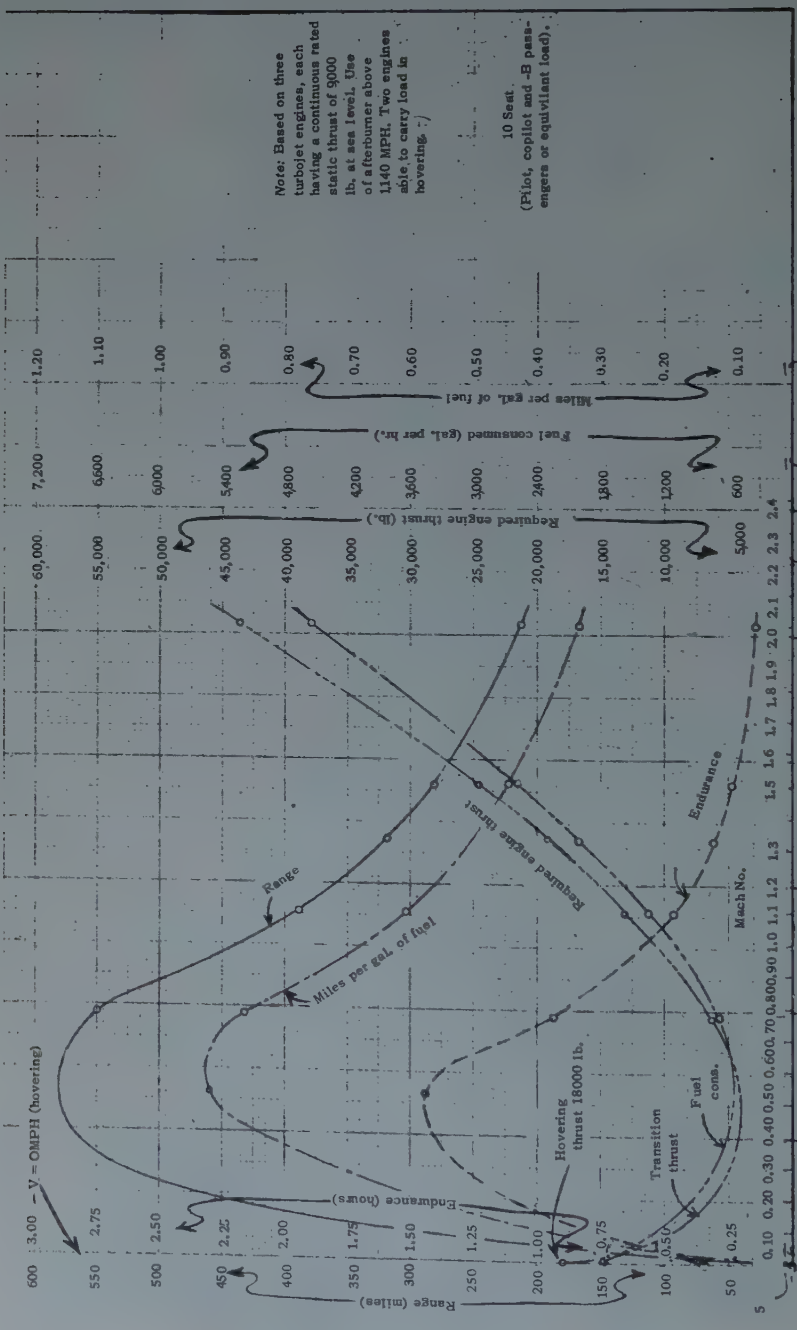


FIGURE 9. Jet-powered rotorless VTOL, 18,000-lb. gross weight, 10 seat: performance curves.

TABLE 1

JET-POWERED ROTORLESS VTOL: 1800-LB. GROSS WEIGHT, 2-SEAT PERFORMANCE CALCULATIONS

Sea level

Hovering: fuel consumption and endurance - General Electric J85 turbojet engine {2000 lb. net static thrust - continuous}

Fuel available = 600 lb. (pilot and passenger)

Gross weight at start of flight = 1800 lb.; at end of flight = 1800 − 600 = 1200 lb.

(required engine thrust)

Average thrust start and end of flight = $\frac{1800 + 1200}{2}$ = 1500 lb. = $\frac{1500}{2000}$ = 0.75

SFC - specific fuel consumption, sea level, static at 75% normal = 0.854 lb./hr./lb. thrust

Fuel consumed: = 1500 × 0.854 = 1280 lb./hr. × $\frac{1}{6.67}$ = 192 gal./hr.

Endurance in hr.: = $\frac{\text{fuel available}}{\text{fuel consumed/hr.}} = \frac{600}{1280}$ = 0.47 hr. × 60 = 28.1 min.

Forward flight: (typical for 200 mph) - sea level

V — aircraft speed, mph = 200 mph × 147 = 294 FPS

M — flight Mach no. (sea level) = $\frac{200}{760}$ = 0.263

Impact pressure (dynamic) $Q = \frac{1}{2}PV^2$ = 103 lb./sq. ft.

C_L = coeff. = $\frac{\text{lift}}{A_F\,Q} = \frac{\text{gross wt.}}{\text{wing area (effective)} \times Q} = \frac{1800}{28.6 \times Q}$ = 0.612

C_o = coeff. of drag = 0.03 +

α_F = fixed wing angle of attack = 8°

$\frac{L}{D}$ = 20.3

} corresponding to C_L above (NACA report no. 627) (for 23013 - 43010 tapered wing.)

1 — D_F = drag of fixed wing = $\frac{L}{\frac{L}{D}} = \frac{1800}{\frac{L}{D}}$ = 88.6 lb.

2 — D_{Po} = {parasitic drag of fuselage and engine compartment = $(C_{D_o} \times A)\,Q$} = 140.5 lb. — ⟨A = frontal area = 31.65 sq. ft.; drag coeff. C_{D_o} = 0.043⟩

3 — Parasitic drag of tail surfaces = 4.0 lb. — ⟨area tail surfaces add. −5.3 sq. ft.; drag. coeff. = 0.0075⟩

Total drag of machine = 1 + 2 + 3 = 233.1 lb. = required engine thrust.

Fuel available = 600 lb. (pilot and passenger)

Reduced lift of fixed wing at end of flight = fuel available

Reduced drag of fixed wing at end of flight = $\frac{600}{\frac{L}{D}}$ = 30 lb.

Reduced horizontal thrust at end of flight = 233 − 30 = 203 lb.

Average horizontal thrust = $\frac{233 + 203}{2} = \frac{218}{1}$ lb. (start and end of flight)

SFC = 1.95 lb./hr./lb. thrust (assumed for 218 × $\frac{1}{1660}$ = 13.1% of net rated thrust) (at Mach 263 corrected.)

Fuel consumed: = 218 × 1.95 = 425 lb./hr. × $\frac{1}{6.67}$ = 64 gal./hr.

Endurance in hr. = $\frac{\text{fuel available}}{\text{fuel consumed/hr.}} = \frac{600}{425}$ = 1.41 hr. × 60 = 84.6 min.

Range: = V × time = 200 × 1.41 = 282 miles

Miles/gal. of fuel; = $\frac{\text{V-mph}}{\text{fuel cons. gal./hr.}} = \frac{200}{64}$ = 3.12 miles/gal.

TAPLE 2

JET-POWERED ROTORLESS VTOL:
1800-LB. GROSS WEIGHT, 1-SEAT PERFORMANCE CALCULATIONS

Sea level

Hovering: fuel consumption and endurance - General Electric J85 turbojet engine 2000 lb. net static thrust - continuous

Fuel available = 800 lb. (pilot only)

Gross weight at start of flight = 1800 lb.; at end of flight = 1800 − 800 = 1000 lb.
(required engine thrust)

Average thrust start and end of flight $= \frac{1800 + 1000}{2} = 1400$ lb. $= \frac{1400}{2000} = 0.70$

SFC - specific fuel consumption, sea level, static = 0.854 lb./hr./lb. thrust (at 70% normal)

Fuel consumed: $= 1400 \times 0.854 = 1200$ lb./hr. $\times \frac{1}{6.67} = 180$ gal./hr.

Endurance in hr.: $\frac{\text{fuel available}}{\text{fuel consumed/hr.}} = \frac{800}{1200} = 0.67$ hr. $\times 60 = 40$ min.

Forward flight: (typical for 200 mph) - sea level

V - aircraft speed, mph $= 200$ mph $\times 1.47 = 294$ FPS

M - flight Mach no. (sea level) $= \frac{200}{760} = 0.263$

Impact pressure (dynamic) $Q = \frac{1}{2}PV^2$ $= 103$ lb./sq. ft.

C_L = coeff. $= \frac{\text{lift}}{A_F\, Q} = \frac{\text{gross wt.}}{\text{wing area (effective)} \times Q}$ $= \frac{1800}{28.6 \times Q} = 0.612$

C_o = coeff. of drag $= 0.03 +$

α_F = fixed wing angle of attack $= 8^{\circ}$

$\frac{L}{D} =$ $= 20.3$

corresponding to C_L above (NACA report no. 627) (for 23013 - 43010 tapered wing.)

1 — D_F = drag of fixed wing $= \frac{L}{\frac{L}{D}} = \frac{1800}{\frac{L}{D}}$ $= 88.6$ lb.

2 — D_{P_o} = parasitic drag of fuselage and engine compartment $= (C_{D_o} \times A)Q$ $= 140.5$ lb. ($A=$ frontal area $= 31.65$ sq. ft.; drag coeff. $C_{D_o} = 0.043$)

3 — Parasitic drag of tail surfaces $= 4.0$ lb. (area tail surfaces add. —5.3 sq. ft.; drag coeff. $= 0.0075$)

Total drag of machine $= 1 + 2 + 3$ $= 233.1$ lb. = required engine thrust.

Fuel available = 800 lb. (picot only)

Reduced lift of fixed wing at end of flight = fuel available

Reduced drag of fixed wing at end of flight $= \frac{800}{\frac{L}{D}}$ $= 40$ lb.

Reduced horizontal thrust at end of flight $= 233 - 40$ $= 193$ lb.

Average horizontal thrust $= \frac{233 + 193}{2} = 213$ lb. (start and end of flight)

SFC = 1.95 lb./hr./lb. thrust (assumed for $213 \times \frac{1}{1660} = 12.9\%$ of net rated thrust Mach 263 corrected)

Fuel consumed: $= 213 \times 1.95 = 415$ lb./hr. $\times \frac{1}{6.67} = 62.3$ gal./hr.

Endurance in hr. $= \frac{\text{fuel available}}{\text{fuel consumed/hr.}} = \frac{800}{415} = 1.93$ hr. $\times 60 = 116$ min.

Range: $= V \times \text{Time} = 200 \times 1.93$ $= 386$ miles

Miles/gal. of fuel: $= \frac{\text{V-mph}}{\text{fuel cons. gal./hr.}} = \frac{200}{62.3} = 3.21$ miles/gal.

twofold and resulting in lower jet velocity in lower temperature and noise level and in greater thrust and lower specific fuel consumption (SFC). The tailcone of the J85 turbojet is shown in dotted lines so that the over-all length of the two engines can be compared. There is also tabulated for the two engines the maximum thrust (continuous, sea-level

TABLE 3

JET-POWERED ROTORLESS VTOL:
18,000-LB. GROSS WEIGHT, 10-SEAT PERFORMANCE CALCULATIONS

Sea level

Hovering: fuel consumption and endurance
Fuel available = 4250 lb. (pilot, copilot and 8 passengers) — {3 turbojet engines - each of 9000 lb. net static thrust - continuous. 2 engines take load in hovering.}

Gross weight at start of flight (required engine thrust) = 18000 lb.; at end of flight = 18000 − 4250 = 13750 lb.

Average thrust start and end of flight $= \frac{18000 + 13750}{2} = 15875$ lb.

SFC - specific fuel consumption, sea level, static = 0.75 lb./hr./lb. thrust

Fuel consumed: $= 15875 \times 0.75 = 11906$ lb./hr. $\times \frac{1}{6.67} = 1792$ gal./hr.

Endurance in hr. $= \frac{\text{fuel available}}{\text{fuel consumed/hr.}} = \frac{4250}{11906} = 0.356$ hr. $\times 60 = 21.4$ min.

Forward flight: (typical for 833 mph) - sea level

	V - aircraft speed, mph	$= 833$ mph $\times 1.47 = 1222$ FPS
	M - flight Mach no. (sea level)	$= \frac{833}{760} = 1.1$
	Impact pressure (dynamic) $Q = \frac{1}{2}PV^2$	$= 1782$ lb./sq. ft.
	C_L = coeff. $= \frac{\text{lift}}{A_F Q} = \frac{\text{gross wt.}}{\text{wing area} \times Q \text{ (effective)}}$	$= \frac{18000}{447.5 \times Q} = 0.0226$
	C_D = coeff. of drag	$= 0.01$ ‡ — corresponding to C_L above (NACA report no. 627) (for 23013 − 43010 tapered wing)
	α_F = fixed wing angle of attack	$= -1^{\circ}$
	$\frac{L}{D} =$	$= 2.26$
1	D_F = Drag of fixed wing $= \frac{L}{\frac{L}{D}} = \frac{L}{\frac{L}{D}} = \frac{18000}{\frac{L}{D}}$	$= 7970$ lb.
2	D_{Po} = ⟨parasitic drag of fuselage and engine compartment $= (C_{Do} \times A)Q$⟩	$= 5075$ lb. ⟨A= frontal area = 66.2 sq. ft. drag coeff. $C_{Do} = 0.043$⟩
3	Parasitic drag of tail surfaces	$= 84$ lb. ⟨area tail surfaces add. 6.3 sq. ft. drag coeff. = 0.0075⟩
	Total drag of machine = 1 + 2 + 3	$= 13129$ lb. = required engine thrust (less than 2 engine thrust)

Fuel available = 4250 lb. (pilot, copilot and 8 passengers)

Reduced lift of fixed wing at end of flight = fuel available

Reduced drag of fixed wing at end of flight $= \frac{4250}{\frac{L}{D}} = 1880$ lb

Reduced horizontal thrust at end of flight $= 13129 - 1880 = 11249$ lb.

Average horizontal thrust $= \frac{13129 + 11249}{2} = \underline{12189 \text{ lb.}}$ (start and end of flight)

SFC = 0.75 lb./hr./lb. thrust (assumed average)

Fuel consumed: $= 12189 \times 0.75 = 9150$ lb./hr. $\times \frac{1}{6.67} = 1370$ gal./hr.

Endurance in hr. $= \frac{\text{fuel available}}{\text{fuel consumed/hr.}} = \frac{4250}{9150} = 0.465$ hr. $\times 60 = 27.9$ min.

Miles/gal. of fuel $= \frac{\text{V-mph}}{\text{fuel con. gal./hr.}} = \frac{833}{1370} = 0.608$ miles/gal.

Range: V × time $= 833 \times 0.465 \cong 388$ miles

$\frac{H}{D}$	$\frac{L_E}{L}$	$\frac{L}{L_{MAX.}}$	$\frac{L_E}{L_{E(MAX.)}}$
0.31	3.0	0.50	0.60
0.62	2.0	1.0	0.80
0.93	2.0	1.0	0.80
1.24	2.0	1.0	0.80
1.55	2.5	1.0	1.0
1.86	2.5	1.0	1.0
2.48	2.5	1.0	1.0
3.72	2.5	1.0	1.0
4.96	2.5	1.0	1.0
7.44	2.5	1.0	1.0

Symbols:

H - Height above ground.

D - Diameter.

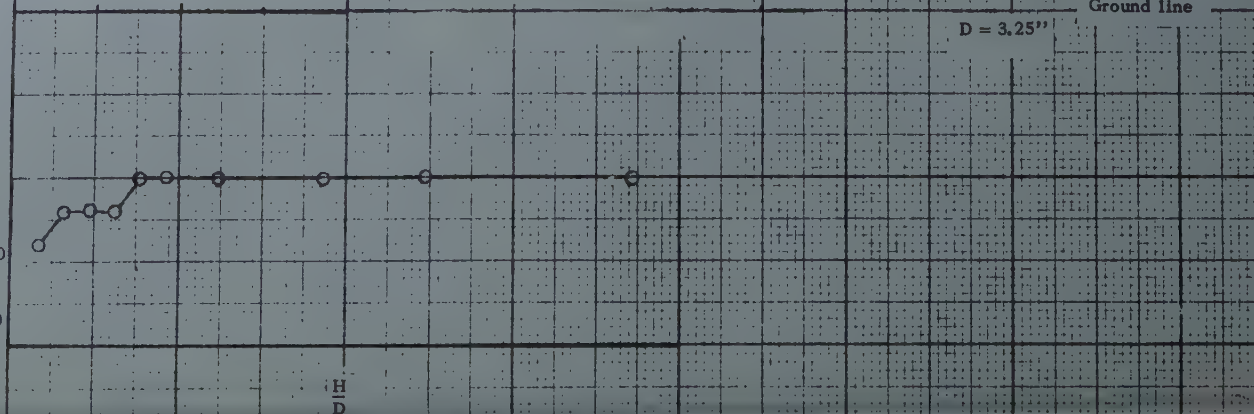
L_E - Lift or thrust with "ejector effect". (split plate removed).

L - Lift or thrust *without* "ejector effect." (split plate in place).

$\frac{L_E}{L}$ - Lift or thrust augmentation by "ejector effect."

$\frac{L}{L_{MAX.}}$ - Relative lift or twist with "ground effect".

$\frac{L_E}{L_{E(MAX.)}}$ - Relative lift or twist with "ground effect".



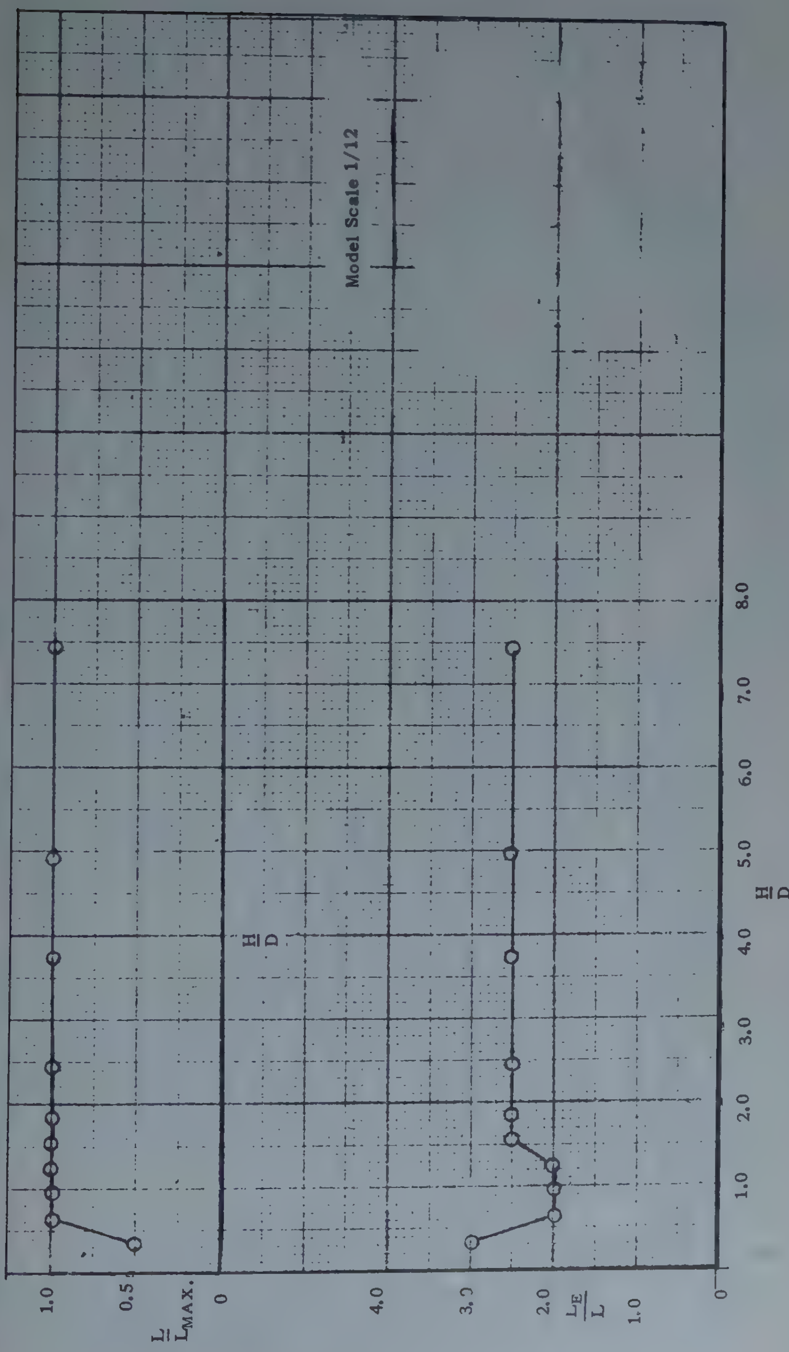


FIGURE 10. Jet-powered rotorless VTOL, 1800-lb. gross weight: 1/12-scale model test results for "ejector effect" and "ground effect."

static), diameter, weight, SFC (continuous, sea-level static), thrust-to-weight ratio, and thrust-to-frontal area ratio. It should be noted that the ratio values are greater for the basic turbojet engine and that there are less rotating parts and bearings, making it less costly and requiring less maintenance.

Applying the ejector-effect test results to the values tabulated in FIGURE 11: to match the 3770-lb. thrust of the turbofan engine will require a turbojet engine of 1885-lb. thrust for an augmentation value 2.0 and a turbojet engine of 1508-lb. thrust for an augmentation value 2.5. These thrust values at a SFC of 0.95 for the J85 turbojet engine show a fuel consumption of 1791 lb./hr. and 1433 lb./hour respectively for the smaller turbojet engines that require no additional moving parts. These values compare to a fuel consumption of 2601 lb./hour for the turbofan engine. It is obvious from these figures that the turbojet engine with ejector effect is preferred for improved performance.

FIGURE 12 is a photograph of a one-twelfth-scale experimental dynamic model of the 1800-lb. gross weight rotorless VTOL aircraft (shown in FIGURE 5) suspended in a 20 inch × 33 inch wind tunnel.

FIGURE 13 is a photograph of the one-twelfth-scale experimental dynamic model hookpup (shown in FIGURE 10) that tests ejector effect and ground effect. Two freely swinging, gimbal-mounted, vertical exhaust nozzles are also shown at *A* on the platform.

FIGURE 14 is a photograph of a schematic hook-up of an experimental dynamic model of a rotorless VTOL. The model is gimbal-mounted to test response to air-pressure jets placed about all three axes. The air receiver holds air at 40 psig, which is supplied by a compressor behind the receiver. Freely suspended, gimbal-mounted, vertical exhaust nozzles shown in FIGURE 13 were connected to study their behavior under air pressure while connected to a control stick; these responded satisfactorily.

FIGURE 15 is a photograph of the one-twelfth-scale experimental dynamic model of the 1800-lb. gross weight rotorless VTOL aircraft (shown in FIGURES 5 and 12) suspended in a 20-inch × 33-inch wind tunnel. Wind is passing through the tunnel at about 18 mph. A small anemometer, as well as a 6-inch scale, is shown at the right near the bottom of the wind tunnel. Compressed air at 40 psig is supplied to the model through a vertical pipe.

Concluding Remarks

Propulsion systems for helicopters and other VTOL aircraft, as well as the desirability of eliminating rotors because of their complexity, added weight, and cost, have been discussed. A new concept for high-speed, simple, jet-powered, rotorless, ejector-thrust-augmented VTOL

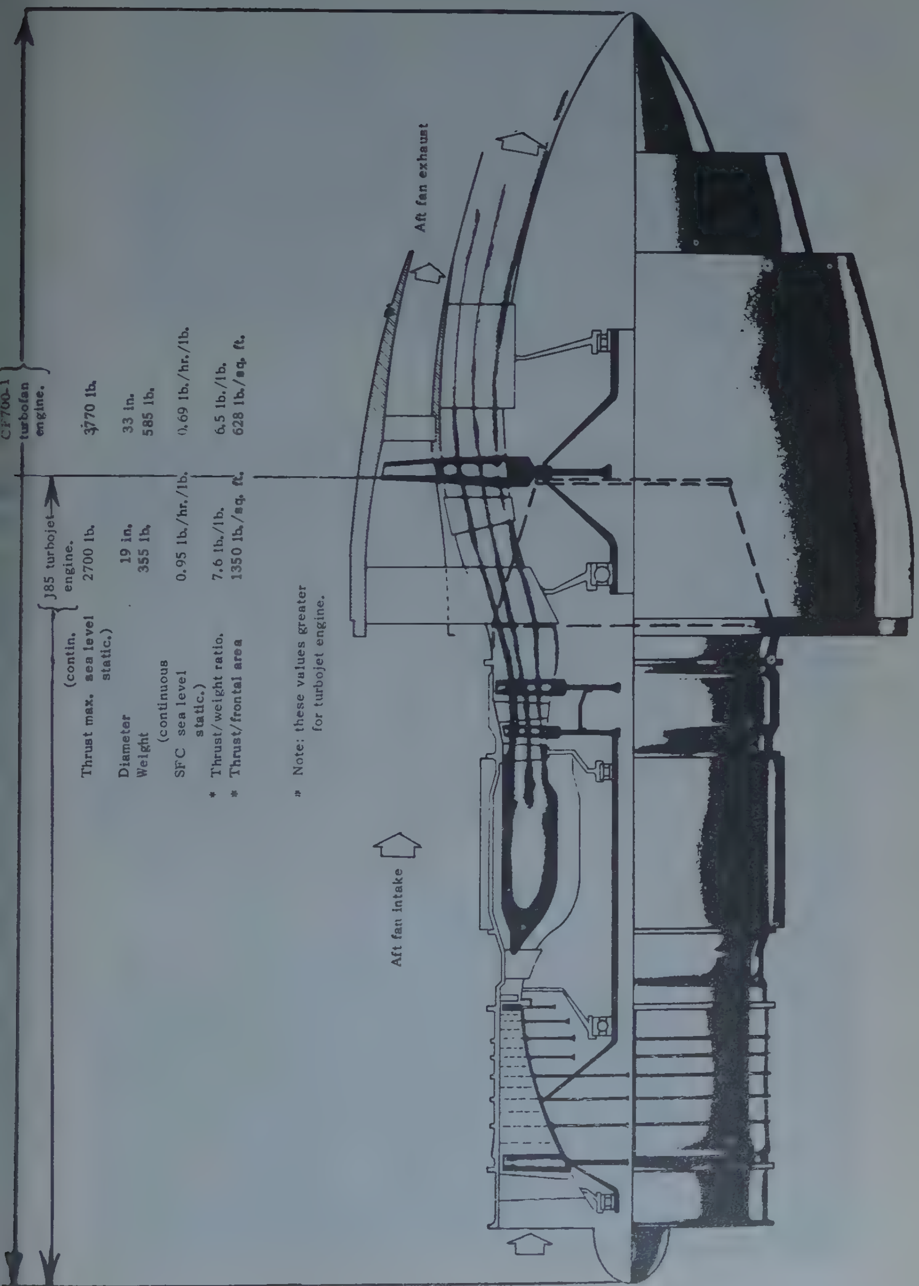


FIGURE 11. Comparison of General Electric J85 turbojet and CF 700-1 turbofan engines.

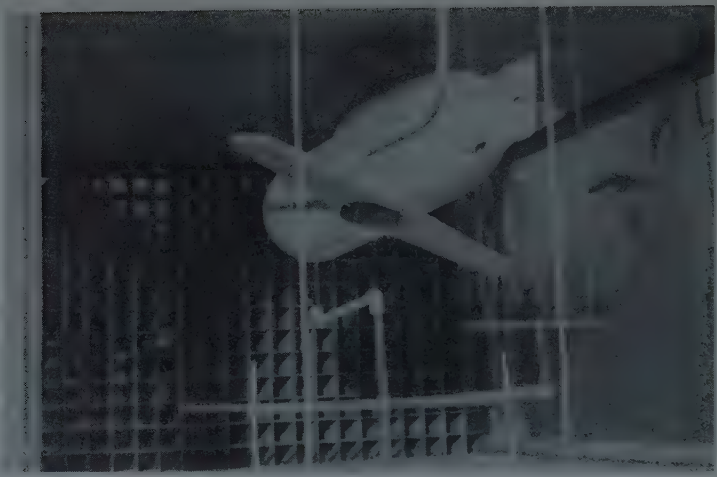


FIGURE 12. Jet-powered rotorless VTOL, 1800-lb. gross weight: 1/12-scale Experimental dynamic model in 20 in.$\times$ 33 in. Wind Tunnel.

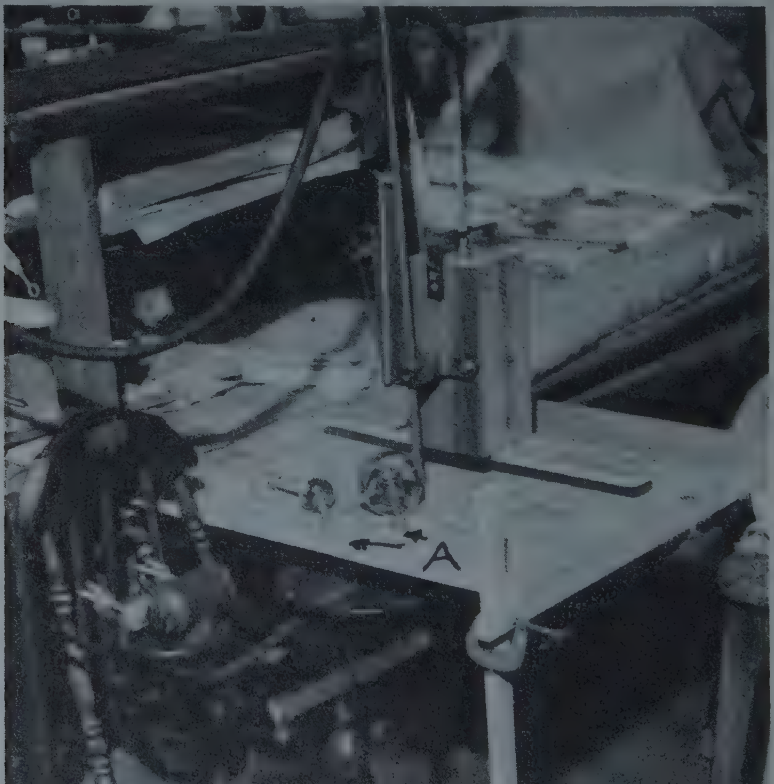


FIGURE 13. Jet-powered rotorless VTOL, 1800-lb gross weight: 1/12-scale model hook-up to test "ejector effect" and ground effect." Gimbal-mounted exhaust nozzles also are shown at *A*.

aircraft, with a minimum of rotating parts, has been described and illustrated. The new concept has the most desirable feature of inherent (hands-off-control stick) stability under all flight conditions. This stability is achieved by mechanical means, namely, a freely suspended, gimbal-mounted vertical exhaust nozzle.

The application of the turbojet engine to rotorless VTOL aircraft of 1800-lb. and 18,000-lb. gross weight has been described and shown. Anticipated performance curves and calculations, without ejector-thrust augmentation, in hovering and forward flight up to Mach No. 2 speed has

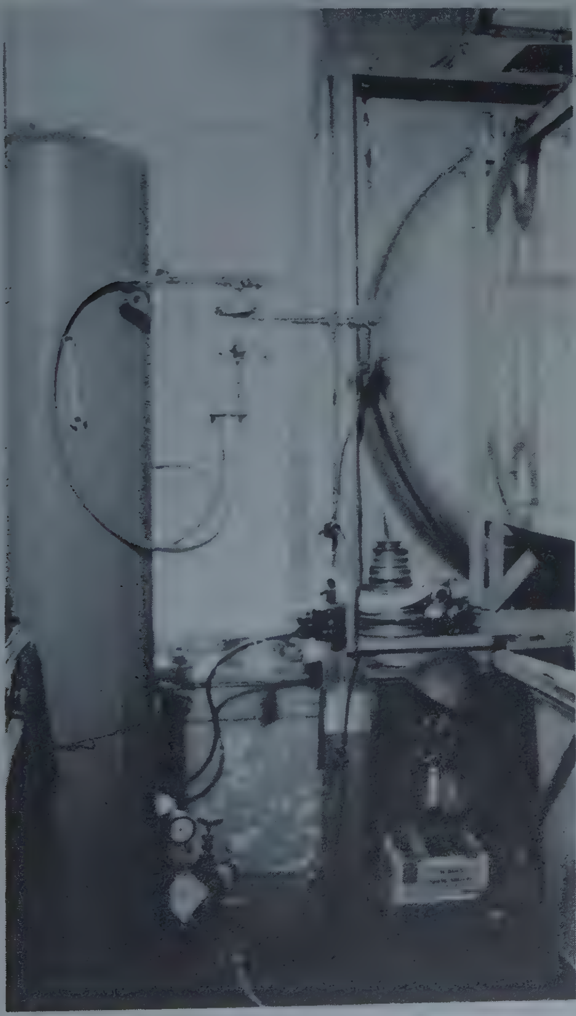


FIGURE 14. Schematic hook-up, jet-powered rotorless VTOL experimental model; gimbal-mounted to test response to pressure jets about all three axes.

FIGURE 15. Jet-powered rotorless VTOL, 1800-lb. gross weight: 1/12-scale model in 20 in. × 33 in. wind tunnel, compressed air to model and wind.

been given. Simple experimental dynamic models testing the soundness of principles involved in the new concept have been shown and described with test results of ejector effect and ground effect on lift or thrust augmentation. A maximum thrust augmentation of 2.5 was obtained at a minimum height of H/D = 1.55. A thrust augmentation of 2.0 was obtained at a height of H/D = 0.93. Performance characteristics (thrust, endurance, range, and fuel consumption) with the basic turbojet engine are improved 2.0 to 2.5 times with ejector-effect augmentation. The comparative characteristics of the turbojet and turbofan engines indicate that the turbojet engine with ejector effect is preferred because of better performance and fewer rotating parts.

The new VTOL concept holds considerable promise and potential for widespread military and commercial application.

References

1. LASKOWITZ, I. B. 1959. Helicopters, a decade of progress, 1949-1959. Municipal Engineers Journal, City of New York. 45. New York, N. Y.
2. SUTTON, J. F. 1960. A propulsion system for reconnaissance aircraft. IAS Paper No. 60-42.
3. NEWSOM, W. A., JR. 1960. Effect of ground proximity on aerodynamic characteristics of two horizontal-attitude jet vertical-take-off-and-landing airplane models. NASA Technical Note D-419.
4. GUSTAFSON, F. B. & R. J. TAPSCOTT. 1954. Method for Obtaining Desired Helicopter Stability Characteristics. NACA Research Memorandum L54F30.
5. VAGUE, M. & C. M. SEIBEL, 1959. Helicopter stabilization and handling characteristics improvement by mechanical means. IAS Paper No. 59-27.

Printed in the United States of America

MONOGRAPHIC PUBLICATIONS

OF

THE NEW YORK ACADEMY OF SCIENCES

(Lyceum of Natural History, 1817–1876)

(1) The Annals (octavo series), established in 1823, contain the scientific contributions and reports of researches, together with the records of meetings of the Academy. The articles that comprise each volume are printed separately, each in its own cover, and are distributed immediately upon publication. The prices of the separate articles depend upon their length and the number of illustrations, and may be ascertained upon application to the Executive Director of the Academy.

Current numbers of the Annals are sent free to all Members of the Academy desiring them.

(2) The Special Publications, established in 1939, are issued at irregular intervals as cloth-bound volumes. The price of each volume will be advertised at time of issue.

(3) The Memoirs (quarto series), established in 1895, are issued at irregular intervals. It is intended that each volume shall be devoted to monographs relating to some particular department of science. Volume I, Part 1 is devoted to Astronomical Memoirs, Volume II to Zoological Memoirs. No more parts of the Memoirs have been published to date. The price is one dollar per part.

(4) The Scientific Survey of Porto Rico and the Virgin Islands (octavo series), established in 1919, gives the detailed reports of the anthropological, botanical, geological, paleontological, zoological, and meteorological surveys of these islands.

Subscriptions and inquiries concerning current and back numbers of any of the publications of the Academy should be addressed to

EXECUTIVE DIRECTOR
The New York Academy of Sciences
2 East Sixty-third Street
New York 21, N. Y.

NOTICE

THIS VOLUME IS INCOMPLETE

THE FOLLOWING ISSUES ARE ON ORDER:

VOL. 93 ART. 2
3